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Using MODIS derived *f*PAR with ground based flux tower measurements to derive the light use efficiency for two Canadian peatlands

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Abstract

We used satellite remote sensing data; fraction of photosynthetically active radiation absorbed by vegetation (fPAR) from the Moderate Resolution Imaging Spectroradiometer (MODIS) in combination with tower eddy covariance and meteorological measurements to characterise the light use efficiency parameter (ε) variability and the maximum ε (ε_{max}) for two contrasting Canadian peatlands. Eight-day MODIS fPAR data were acquired for the Mer Bleue (2000 to 2003) and Western Peatland (2004). Flux tower eddy covariance and meteorological measurements were integrated to the same eight-day time stamps as the MODIS fPAR data. A light use efficiency model: GPP=ε * APAR (where GPP is Gross Primary Productivity and APAR is absorbed photosynthetically active radiation) was used to calculated ε. The ε_{max} value for each year (2000 to 2003) at the Mer Bleue bog ranged from 0.58 g C MJ^{-1} to 0.78 g C MJ^{-1} and was 0.91 g C MJ^{-1} in 2004, for the Western Peatland. The average growing season ε for the Mer Bleue bog for the four year period was 0.35 g C MJ^{-1} and for the Western Peatland in 2004 was 0.57 g C MJ^{-1}. The average snow free period ε for the Mer Bleue bog over the four year period was 0.27 g C MJ^{-1} and for the Western Peatland in 2004 was 0.39 g C MJ^{-1}. Using the light use efficiency method we calculated the ε_{max} and the annual variability in ε for two Canadian peatlands. We determined that temperature was a growth-limiting factor at both sites Vapour Pressure Deficit (VPD) however was not. MODIS fPAR is a useful tool for the characterization of ε at flux tower sites.

1 Introduction

Northern peatlands contain approximately one third of global soil carbon (Gorham 1991). They have been accumulating carbon for the last 6000 to 10 000 years of the Holocene (Vitt et al., 2000; Gorham et al., 2003). Few multi-year flux measurement programs have been conducted on peatland ecosystems (e.g. Lafleur et al., 2001; Arneth et al., 2002; Aurela et al., 2002; Lafleur et al., 2003), but available data suggest that carbon accumulation continues to occur. Peatlands accumulate carbon because net primary productivity (NPP), on average, exceeds decomposition. NPP in peatlands is not particularly large, but decomposition rates are low because the high water content reduces oxygen diffusion into litter and surface horizons and the litter of the plant types that grow on many peatlands, particularly bogs, is not readily decomposed (Malmer and Wallén, 2004).

Climate simulations have indicated that higher latitudes will probably experience warming and changes in available moisture (precipitation-evapotranspiration) (Albritton and Meira Filho, 2001), which has raised concern over whether the environmental conditions conducive to peatland carbon accumulation will be sustained in the future (e.g. Moore et al., 1998). Many of these peatland types are located in remote areas of the boreal and subarctic climatic zones therefore tools that utilise remotely sensed data to infer changes in ecosystem productivity and net carbon exchange would be very useful. Remote sensing can be used to estimate NPP over large areas (Running et al., 1999; Ahl et al., 2004). While there has been considerable effort to develop these types of tools for forested and cropland ecosystems (e.g. Potter et al., 1993, Turner et al., 2002, 2003; Ahl et al., 2004) peatlands have received little attention.

Monteith (1972) first proposed an approach to relate fPAR to biomass production that became known as the light use efficiency (LUE) model (Hunt, 1994; Gower et al., 1999; Brogaard et al., 2005). The LUE model of gross primary production (GPP in $\mathrm{g\,C\,m^{-2}\,d^{-1}}$) is generally given as:

$$\mathrm{GPP} = \varepsilon * \mathrm{APAR} \tag{1}$$

where ε is the light use efficiency parameter (g C $\mathrm{MJ^{-1}}$) and APAR is MJ $\mathrm{m^{-2}\ d^{-1}}$. APAR is generally given as:

$$\mathrm{APAR} = \downarrow\mathrm{PAR} * \mathrm{fPAR} \tag{2}$$

where $\downarrow$PAR is incident photosynthetically active radiation and fPAR is a fraction of photosynthetically active radiation that is absorbed.

*f*PAR is a key biological property that is important for estimating canopy photosynthesis (Goetz et al., 1999; Seaquist et al., 2003) because it characterizes vegetation canopy function and energy absorption capacity (Myneni et al., 2002, 2003; Wang et al., 2001). It is a measure of the proportion of available radiation in the photosynthetically active wavelengths (0.4 to 0.7 mm) that a canopy absorbs (Savtchenko et al., 2003; Myneni et al., 2003; Fensholt et al., 2004). *f*PAR is also the radiometric equivalent of leaf area index (Running et al., 2000).

Early studies assumed that LUE or ε was constant. Monteith's (1972) original theory was designed for well-watered crops only during the growing season (Heinsch et al., 2003). The LUE is based on the positive linear relationship between NPP and absorbed photosynthetically active radiation (APAR). It is used to translate remotely sensed estimates of light absorption into GPP or NPP (Ruimy et al., 1994; Lobell et al., 2002). However ε has been shown to vary spatially between biomes, ecosystems, and plant species, and temporally over the growing season even within spatially homogeneous vegetation canopies (Ruimy et al., 1994; Turner et al., 2002; Brogaard et al., 2005). Photosynthesis and respiration are strongly sensitive to environmental controls such as VPD and air temperatures (Fan et al., 1995; Kimball et al., 2000). Heinsch et al., (2003), extrapolated the LUE theory to perennial plants living throughout the year and thus were subject to stresses such as temperature and VPD. Low temperatures affect plants abilities to photosynthesis and a high VPD has been shown to inhibit photosynthesis by causing stomata to close (Heinsch et al., 2003). Estimates of GPP from LUE models may be improved if vegetation association or ecosystem level specific parameter values are used (Goetz and Prince, 1999; Ahl et al., 2004; Coursolle et al., 2006). Several authors have suggested that more work is needed to characterise the spatial and temporal variability in ε (Ruimy et al., 1994; Goetz and Prince, 1998; Gower et al., 1999). This study uses the light use efficiency model approach to estimate a value for ε that has been attenuated by the sub-optimal environmental condition of temperature and vapour pressure deficit. Therefore the objectives of this work were a) to examine how ε varied throughout the growing season and b) to derive a maximum annual

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estimated ε (ε_{max}) for two contrasting Canadian peatlands using MODIS derived *f*PAR.

2 Methods

2.1 Peatland study sites

Two Fluxnet Canada Research Network sites were used in this study, the Eastern (Mer Bleue bog) and Western Peatland sites, both are equipped with eddy covariance flux measurement towers. The Mer Bleue bog is located in the Ottawa valley–St. Lawrence Lowland, Ontario (45°24′N latitude, 75°30′W longitude) (Lafleur et al., 2001). The elevation of the bog is 70 m (Smith and Lafleur, 2003). It is a raised, low-shrub, ombrotrophic bog of 2800 ha (Moore et al., 2002; Bubier et al., 2003). Peat depths range from 5 to 6 m near the tower site to ~2 m at the edges of the bog (Bubier et al., 2003; Lafleur et al., 2003). This bog is representative of raised shrub bogs of the boreal region (Lafleur et al., 2001). The climate of the region is cool continental, with a mean annual temperature of 5.8°C and an annual precipitation of 910 mm (Lafleur et al., 2003). The coldest month is January (–10.8°C) and the warmest July (20.8°C). Over three quarters of the annual precipitation falls as rain and the average growing season (May to September) precipitation is 410 mm (Lafleur et al., 2003). The plant communities on the bog are dominated by ericaceous shrubs and *Sphagnum* mosses with secondary communities consisting of deciduous shrubs, sedges and trees (Bubier et al., 2003). The water table during the growing season over the five years was between 20 and 73 cm beneath the peat surface at the Mer Bleue.

Western Peatland is located in the La Biche River area in Alberta (54°57′N latitude, 112°28′W longitude). The site is a moderately rich treed fen (Syed et al., 2006). The climate of the region is continental, with a mean annual temperature of is 2.1°C and the annual precipitation is 504 mm (Syed et al., 2006). The coldest month is January (–15°C) and the warmest is July (~16°C). The vegetation of the study site was dominated by stunted trees of *Picea mariana* and *Larix laricina*, with high abundance of a shrub, *Betula pumila*, and a wide range of moss species (Syed et al., 2006).

2.2 In situ measurements

The eddy covariance towers collect data that permit daily records of NEE, ER and ↓PAR to be made (Lafleur at al., 2001; Moore et al., 2002, Lafleur et al., 2003 and Syed et al., 2006). Measurements began at Mer Bleue in 1998 and in 2003 at the Western Peatland (Lafleur et al., 2003; Syed et al., 2006). ↓PAR was measured at both sites using quantum sensors (Lafleur et al., 2001; Lafleur et al., 2003; Syed et al., 2006). NEE and ER were measured at the Mer Bleue bog with a closed-path infrared gas analyzer (initially a LI6262 but upgraded in 2002 to a LI7000, LI-COR, Lincoln, NB, USA) (Lafleur et al., 2001, 2003) and at the Western Peatland with a fast response closed-path infra-red gas analyzer (LI7000, LI-COR, Lincoln, NB, USA) (Syed et al., 2006). A number of environmental measurements were also made, at both sites, in support of the flux tower data including air temperature, relative humidity, wind speed, soil temperature and depth to water table from the peat surface were measured at both sites and precipitation, snow depth and atmospheric pressure were measured at the Western peatland. Details of the environmental measurements can be found in Lafleur et al. (2001); Lafleur et al. (2003); Syed et al. (2006). Tower data were assessed for quality assurance and gap-filling techniques were employed, as described by Lafleur et al. (2005) for Mer Bleue and Syed et al. (2006) for the Western Peatland.

Gross primary production (GPP) is the total amount of carbon that is fixed by plants. Approximations of GPP also called GEP (Chapin et al., 2006, Moore et al., 2006) were derived from micrometeorological eddy covariance measurements of gross ecosystem productivity (GEP) i.e., net ecosystem exchange (NEE) minus ecosystem respiration (ER) (Law et al., 2000). NEE is the carbon dioxide exchange of terrestrial ecosystems that is driven by the balance between the sequestration of CO_2 by photosynthesis and its emission by soil and plants i.e. ecosystem respiration (Bubier et al., 2003). GPP was estimated as:

$$\text{GPP} = \text{NEE} - \text{ER} \quad (3)$$

Where GPP = gross primary productivity ($\text{g C m}^{-2}\,\text{d}^{-1}$), NEE=net ecosystem exchange ($\mu\text{mol m}^{-2}\,\text{d}^{-1}$), ER=ecosystem respiration ($\mu\text{mol m}^{-2}\,\text{d}^{-1}$). The flux measurements were collated on a half hourly time step and used to calculate a mean daily value for 8-day time period's consistent with the 8-day composite *f*PAR data from MODIS on the Terra (EOS AM) satellite (Yang et al., 2006). The methodology used in this study required that the field-measured data be compatible with the 8-day time step of the MODIS *f*PAR data, therefore there is a loss of the day-to-day variation (Sims et al., 2005).

2.3 Satellite images

Terra (EOS AM) was launched in 1999 (Salomonson, 2002) and began producing the Moderate Resolution Imaging Spectroradiometer (MODIS) data, including *f*PAR data, in 2000 (Myneni et al., 2002). MODIS has thirty-six spectral bands including middle and long-wave infrared and provides a spatial resolution of 250 m, 500 m and 1 km (Savtchenko et al., 2003; Justice et al., 1998). MODIS collection 4 data were used in this study. The *f*PAR values are composited over an 8-day period and the value used is the highest *f*PAR value in that 8-period (Yang et al., 2006).

Each MODIS *f*PAR image has a pixel resolution of 1 km^2. The footprint of an EC tower is ~1 km^2 (Running et al., 2004) however 80% of the flux comes from within 200 m of the tower site (Lafluer, Perscomm), therefore the measurements from the EC tower (NEE, ER and ↓PAR) and *f*PAR from MODIS were obtained from the same peatland area at each study site and could be used to calculate ε. Both the Mer Bleue bog and the Western Peatland sites were classified as mixed forests in the IGBP MODIS biome classification scheme (Lotsch et al., 2003). However, to test the reliability of MODIS-derived *f*PAR values we used a simple Beers Law approach (Ahl et al., 2005; Turner et al., 2005) with fPAR derived from previously published field measured LAI data for the Mer Bleue bog (Moore et al., 2002 and Sonnetag et al., 2007).

$$\text{Beer's Law(with an extinction coefficient (k) of 0.5)} = 1 - \exp(\text{LAI}(-k)) \tag{4}$$

The algorithm associated with MODIS fPAR uses a simple selection rule whereby the maximum fPAR value over the 8-day period is chosen to be the representative value for the output pixel (Heinsch et al., 2003). The first day of the first compositing period is the 1st January and the first day of the second compositing period is 9th January. The 8-day time step of the MODIS fPAR product was used as a template to calculate ε. Throughout one calendar year there are forty-five full 8-day compositing periods and one 5-day compositing period at the end of the year.

Over 200 MODIS fPAR images were acquired for the Mer Bleue bog site (representing four years of data) and 65 for the Western Peatland site (representing one and a half years of data). The MODIS fPAR data were acquired in the Hierarchical Data Format (.HDF) and converted to Erdas/Imagine format (Doraiswamy, 2002; Heumann, personal communication, 2005). In order to extract the fPAR data it was necessary to pre-process the images in Erdas Imagine. The pre-processing included reprojecting the fPAR images from the MODIS sinusoidal projection to UTM zone 18 for the Mer Bleue bog and UTM zone 12 for the Western peatland with the WGS 84N datum using bilinear interpolation and rigorous transformation to enable extraction of fPAR values for each tower site (Lopes, 2003, Heumann, personal communication, 2005). The data were imported to IdrisiTM and subset to an area around each observation tower. A 1-km^2 mask was created over the tower area and fPAR data were extracted for each tower pixel for all images over the time period.

2.4 Variability in ε

The variability in ε is due to maintenance respiration costs and sub optimal weather conditions (Heinsch et al., 2003). The mean minimum daily temperature (Tmin) and VPD were acquired from both the Mer Bleue bog and the Western Peatland datasets and plotted separately against ε to determine the effects of each on the ε. Saturated VPD was calculated using the following formula (Snyder and Paw, 2006);

$$e_s = \exp\left(\frac{17.27T}{T + 237.3}\right) \quad (5)$$

Where e_s is saturated VPD (kPa) and T=temperature (°C).

The VPD was then calculated from e_s using relative humidity data from both datasets in the following equation:

$$\mathrm{VPD} = \left(e_s - \left(\left(^{\mathrm{RH}}/_{100}\right) * e_s\right)\right) * 1000 \quad (6)$$

Where RH is relative humidity.

3 Results and discussion

All results are presented as mean daily values for each 8-day time step. Data for ↓PAR, *f*PAR and GPP are shown because they are the main constituents for deriving ε and can be used to explain the structure of the derived ε dataset.

3.1 Daily ↓PAR

The plots of ↓PAR against time (Fig. 1a and b) show strong association with Sun-Earth geometry. The maximum average daily ↓PAR for both the Mer Bleue bog and the Western Peatland ranges between 10 to 12 MJ m^{-2} d^{-1}. These values are slightly lower than those reported by Turner et al. (2003), but both peatland sites reported here are located farther north. The data are averaged out over 8-day periods, which mean that the day-to-day variation in ↓PAR is not seen. Peak ↓PAR in 2000 was lower than the following years, perhaps because 2000 was a wetter year *(Bubier et al., 2003*), and therefore cloudier thus leading to a reduction in ↓PAR.

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3.2 MODIS *f*PAR

There is considerable variation in MODIS *f*PAR over each growing season (Fig. 2a and b), however the maximum values for each year are quite similar at about 0.95. These values were consistent with *f*PAR derived from field measured LAI using a simple Beers Law approach Eq. (4):

Both Moore et al. (2002) and Sonnetag et al. (2007) report that typical mid-August LAI values for bog and poor-fen vegetation at the Mer Bleue bog site range from 1.30 to 2.13. Based on these values, the estimated the canopy *f*PAR (derived using Beer's Law with an extinction coefficient of 0.5, $1-\exp(1.3(-0.5))=0.48$ and $1-\exp(2.13(-0.5))=0.66$) would range from 0.48 to 0.66 (Frolking et al., 2002). Assuming moss absorbs 85% of the remaining PAR (Frolking et al., 2002) total canopy *f*PAR would then range from 0.92 to 0.95.

The *f*PAR values are strongly associated with sun-earth geometry, but there is also a strong relationship with snow cover. The increase in *f*PAR at Mer Bleue coincides with the snow melt period in 2001 and 2002 however in 2000 and 2003 when *f*PAR increases there was still around 20 cm of snow on the ground (Roulet et al., 2007). Towards the end of each year there is a downturn in *f*PAR over several compositing periods, probably due to the presence of snow on the bog. The *f*PAR results for the Western Peatland have similar maximum summer values as the Mer Bleue bog at ~0.95.

However the winter values for 2002 and 2003 are very different as there are few very low *f*PAR. Since GPP is very low during this time there is no impact on the ε calculation. The *f*PAR values at the Western Peatland do depict the same trend as those at the Mer Bleue. They do not go to zero during the winter probably because it is a treed fen. The trees will always absorb some PAR and thus rarely go to zero, this is assuming winter starts on Julian day 335 and ends on Julian day 59 then the range of winter *f*PAR values is from 0.09 to 0.40.

A number of data points in Fig. 2a and b, did not conform to expected patterns.

Turner et al. (2005) found *f*PAR to be stable in summer time and therefore large, short-term differences suggest problems with the source data. In early 2001, *f*PAR was reduced to zero for two consecutive 8-day periods due to a malfunction in the MODIS sensor (Wan et al., 2004). During the growing season there are occasions when *f*PAR is low resulting in high ε values. The *f*PAR values may be low for a number of reasons such as cloud contamination (Running et al., 2004) and sensor problems (Myneni et al., 2003). At the Western Peatland low *f*PAR values were present for two consecutive 8-day compositing periods during September 2004. The *f*PAR values for these two periods were 0.19 and 0.01. MODIS QC attributed these low values to failure of the main (RT) method (Myneni et al., 2003).

3.3 Growth limiting factors: VPD and Tmin

VPD was calculated using Eqs. (5) and (6) with the data for both Mer Bleue and the Western Peatland. The VPD for the Mer Bleue was then plotted against ε. At the Mer Bleue the VPD was not a limiting factor on ε (Fig. 3). This may be due to the high water tables found at each site. However, Tmin was a limiting factor on ε at both sites. When Tmin was plotted against ε it was clear that low temperatures affect ε (Fig. 4). When the mean daily temperature drops below -6°C at the Mer Bleue and -10.6°C at the Western peatland it becomes to cold for the plants to function and ε is reduced to zero because the plants are not converting light into GPP.

3.4 Gross Primary Production

GPP was calculated using Eq. (3) and NEE and ER data. The maximum daily 8-day average GPP at Mer Bleue for the four years reported was about 5 g C m^{-2}d^{-1} (Fig. 5a), whereas the maximum for the Western Peatland was about 8.5 g C m^{-2} d^{-1} (Fig. 5b). At both sites there was a seasonal pattern that followed trends in ↓PAR and *f*PAR. GPP is reduced to zero in the winter at both sites because ER equals NEE. GPP starts to accumulate when the snow season ends which is usually at the end of March or early

April for the Mer Bleue bog (Lafleur at al., 2003) and around the same time for the Western Peatland. The peak GPP at Mer Bleue varies between years. It was earlier in the season in 2001 and 2003 than it was 2000 and 2002. The maximum 8-day average GPP values for all years varied from 4.5 $\mathrm{g\,C\,m^{-2}\,d^{-1}}$ to 5 $\mathrm{g\,C\,m^{-2}\,d^{-1}}$, with the highest occurring in 2002. This variation might be attributed to weather conditions e.g. 2000 was a much wetter year than 2001 (Bubier et al., 2003) this can be seen in Fig. 6. where the water table in 2000 is clearly nearer the surface than in 2001. The length of the growing season is similar for both sites but GPP was considerably higher at the treed Western Peatland where the maximum 8-day average GPP value for 2004 was 8.25 $\mathrm{g\,C\,m^{-2}\,d^{-1}}$.

3.5 Light Use Efficiency parameter (ε)

As expected the light use efficiency parameter for both sites followed the seasonal patterns of PAR, *f*PAR and GPP. The maximum ε value for each of the four years at the Mer Bleue bog ranges from 0.71 $\mathrm{g\,C\,MJ^{-1}}$ in 2000 to 0.78 $\mathrm{g\,C\,MJ^{-1}}$ in 2003 (Fig. 7a and b). The maximum value in 2002 was much lower at around 0.60 $\mathrm{g\,C\,MJ^{-1}}$. In order to determine the start, end and time of peak of the growing season for each year a curve was fitted through the data (Fig. 7a and b):

$$\varepsilon' = a + b * cos(ct + d) \tag{7}$$

where ε' = estimated ε parameter value, t=day of year and *a, b, c,* and *d* are fitting parameters. The parameters were interpreted such that *a* and *b* reflect the magnitude of the peak $\varepsilon_{\max}$ value for each year. *c* reflects the length of the growing season (the smaller c is the longer the growing season) and *d* reflects when the peak value occurs (Table 1).

At the Mer Bleue, the growing season begins and ends at a similar time in each year, except 2001, when it ends much later (Fig. 8). At the Western Peatland, it starts slightly later and ends much earlier than at Mer Bleue. The Mer Bleue bog $\varepsilon_{\max}$ is interesting, in 2000 and 2003, the pattern between both curves is almost the same especially around midsummer. In 2002, the pattern is very similar but the ε_{max} is lower. In 2001, a drier than normal year (Bubier et al., 2003), the ε_{max} is later and much lower (Fig. 8). Various weather patterns may explain the differing peaks and growing season lengths, for example 2001 was very dry (Bubier et al., 2003), in Fig. 8, the peak predicted epsilon value on the curve is ~0.41 g C MJ^{-1}, about 0.1 g C MJ^{-1} lower than the other three years. This peak also occurs two to three weeks later than in the other years. The predicted ε_{max} in 2004, for the Western peatland occurs slightly earlier in the year and is ~50% higher than at Mer Bleue. This pattern can also be found in the measured data where ε_{max} at Western Peatland is higher than that at Mer Bleue, 0.91 g C MJ^{-1} versus 0.78 g C MJ^{-1}. The reason for this is due to the greater productivity of trees at the Western peatland site.

Early work with the ε approach assumed a constant ε but later studies have shown that there is variation between biomes and throughout the year (Turner et al., 2003; Ahl et al., 2004; Brogaard et al., 2005). Our results found that ε varied throughout the year and followed a fairly predictable seasonal pattern. The average growing season at Mer Bleue is from May to September and at the Western Peatland is from May to October (Lafleur et al., 2003; Syed et al., 2006).

A number of factors can affect the photosynthetic efficiency of plants, influencing ε, such as in-situ environmental conditions: soil moisture, water table position (Lafleur et al., 2003), nutrient availability and weather conditions. ε (believed to be constant, (Monteith, 1972; Potter et al., 2003) can be attenuated by temperature and vapour pressure deficit (VPD) limitations (Running et al., 2000). An examination of the data used in this study indicated that, for both sites in Canada, low temperatures reduced ε relative to ε_{max} but that VPD had no effect. At Mer Bleue, as the temperature approached −6 to −7°C ε is close to zero and beyond −10 °C ε is reduced to zero. Similarly at the Western Peatland in 2004 as the temperature nears −9.5 °C ε is close to zero and beyond −10.5 °C ε is reduced to zero. The ε_{max} occurs in mid summer and ranges from between 0.58 g C MJ^{-1} and 0.78 g C MJ^{-1} for the Mer Bleue bog for the years 2000 to 2003 and was 0.91 g C MJ^{-1} for the Western Peatland in 2004.

The average ε for the snow free period (April to November) for the Mer Bleue bog over the four years was $0.27\,\mathrm{g\,C\,MJ^{-1}}$ and for the Western Peatland for 2004 was $0.39\,\mathrm{g\,C\,MJ^{-1}}$. The average growing season (May to September, Lafleur et al., 2003) ε for the Mer Bleue bog ranged between $0.32\,\mathrm{g\,C\,MJ^{-1}}$ in 2001 to $0.38\,\mathrm{g\,C\,MJ^{-1}}$ in 2003 and the growing season (May through October, Syed et al., 2006) ε in 2004 for the Western Peatlands was $0.57\,\mathrm{g\,C\,MJ^{-1}}$. These average growing season values are comparable to the growing season value for a forested wetland in northern Wisconsin of $0.37\,\mathrm{g\,C\,MJ^{-1}}$ (Ahl et al., 2004).

4 Conclusions

The LUE was derived for two Canadian peatland sites using satellite and flux tower data. The spatial and temporal variation of ε_{max} between the Western peatland site ($0.91\,\mathrm{g\,C\,MJ^{-1}}$) and the Mer Bleue site ($0.78\,\mathrm{g\,C\,MJ^{-1}}$) may be attributed to differences in the climate and vegetation at each site. There are some truncated records of LAI for the Mer Bleue however there is no LAI data for the Western Peatland therefore the use of satellite derived MODIS *f*PAR, which can be substituted for LAI, is advantageous. Midsummer MODIS *f*PAR performed as expected when were compared to LAI derived*f*PAR calculated using Beer's law and published data for the Mer Bleue. This method which combines satellite data with flux tower observations could lead to the characterisation of ε and ε_{max} not only for other peatlands but also for different biomes.

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Table 1. The parameter values for the curves estimating growing season length, peak and peak occurrence.

	Mer Bleue				Western Peatland
Parameters	**2000**	**2001**	**2002**	**2003**	**2004**
a	0.218	0.178	0.2	0.198	0.389
b	0.235	0.195	0.215	0.219	0.447
c	0.018	0.015	0.017	0.017	0.019
d	−3.733	−3.374	−3.736	−3.539	−4.164

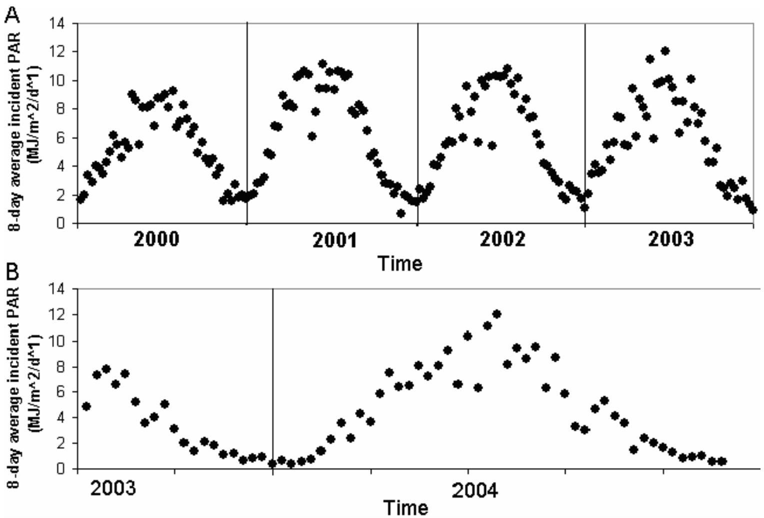

Fig. 1. Average daily ↓PAR for an 8-day time step for **(A)** 2000–2003 for the MerBleue bog, Ontario, and **(B)** from 2003–2004 for the Western Peatland, Alberta.

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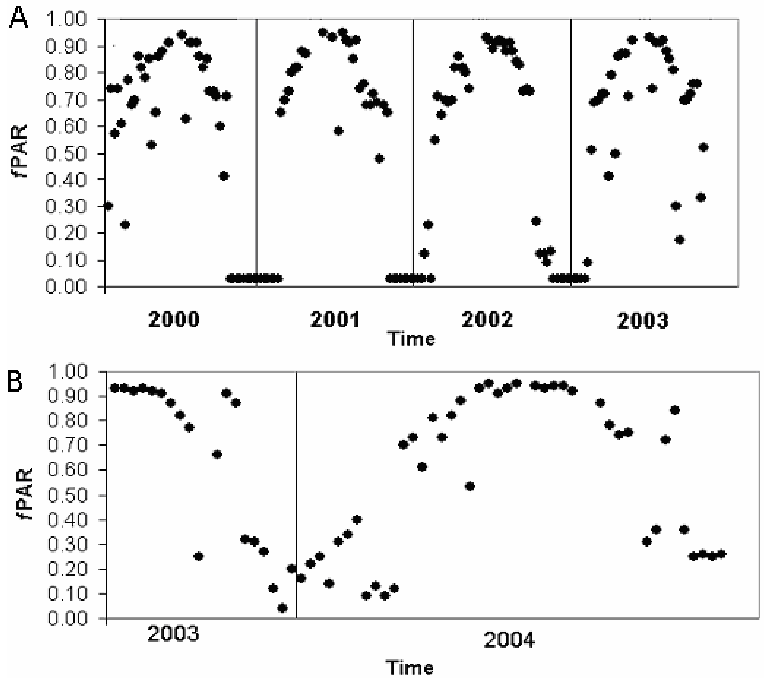

Fig. 2. MODIS *f*PAR data for **(A)** 2002 to 2003 for Mer Bleue bog, Ontario and **(B)** 2003–2004 for Western Peatland, Alberta.

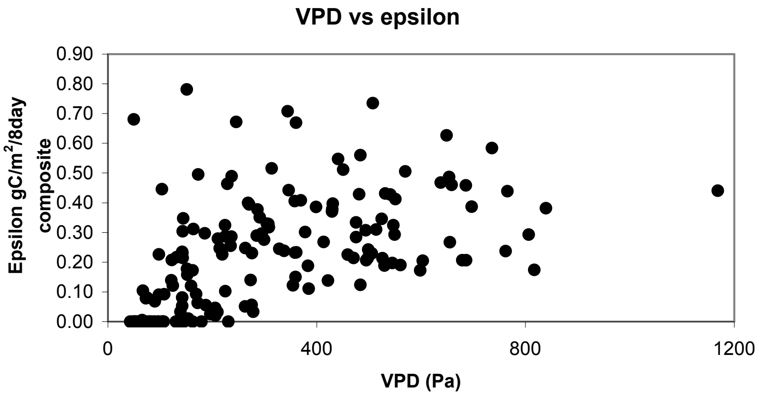

Fig. 3. The relationship between Epsilon and VPD at the Mer Bleue.

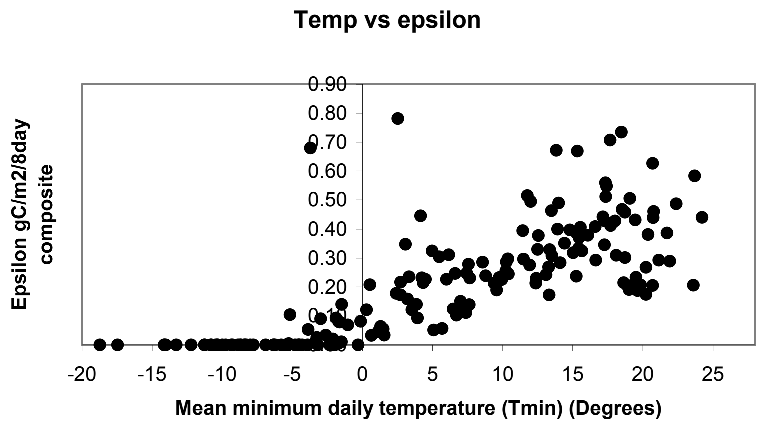

Fig. 4. The relationship between Mean minimum daily temperature (Tmin) and Epsilon.

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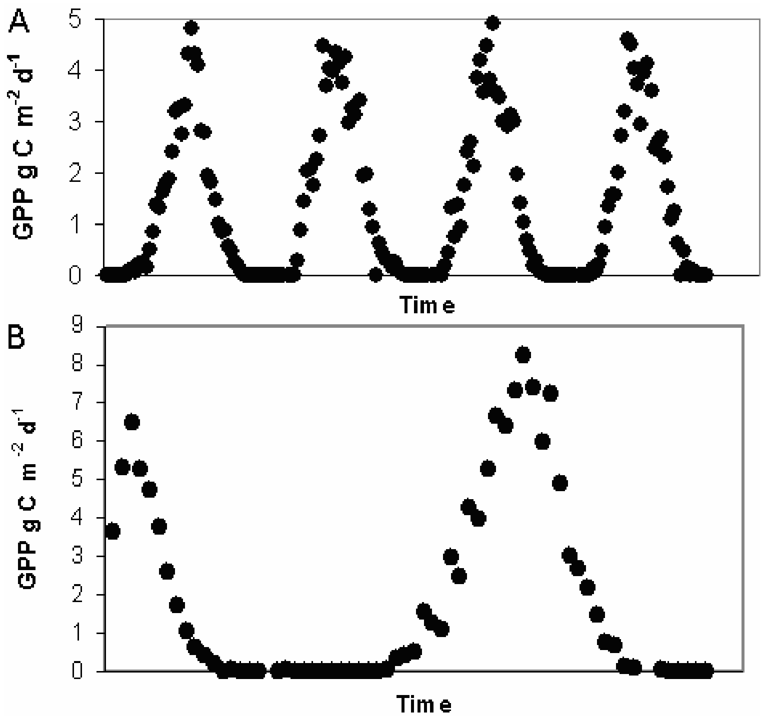

Fig. 5. Average daily GPP for an 8-day time step for **(A)** 2000–2003 for the Mer Bleue bog, Ontario, and **(B)** 2003 for the Western Peatland, Alberta.

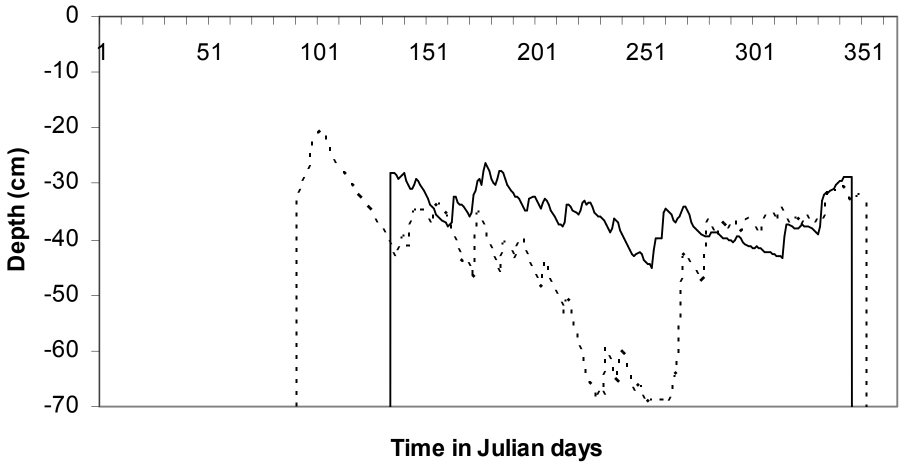

Fig. 6. Water table in 2000 (solid line) versus 2001 (Dashed line).

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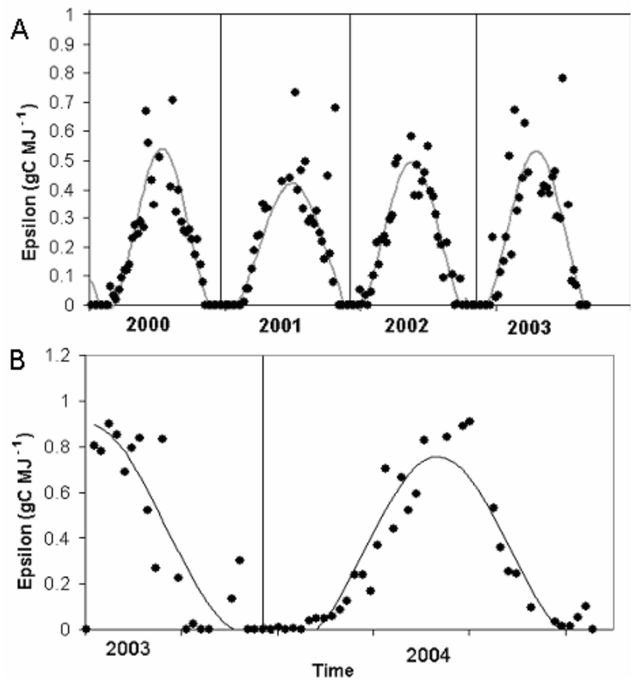

Fig. 7. Estimate the length of the growing season and the peak ϵ for **(A)** 2000 to 2003 at Mer Bleue and **(B)** 2003 to 2004 at Western Peatland. The line indicates the fit of Eq. (5).

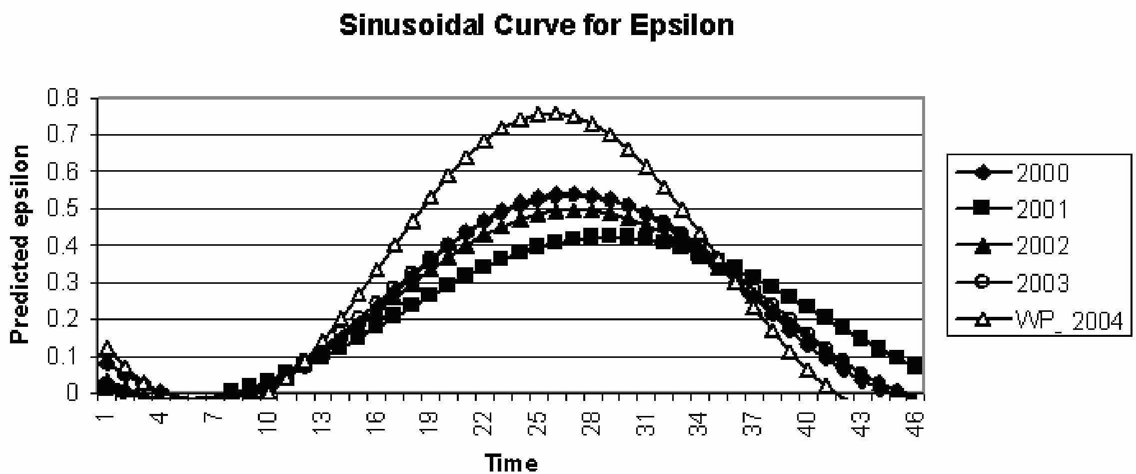

Fig. 8. Predicated curves estimating the length of the growing season, the peak value ϵmax, and the peak occurrence. (♦=MB_2000, ■=MB_2001, ▲=MB_2002, ○=MB_2003 and △=WP_2004.)